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VERITAS: Status and Latest Results

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Abstract: VERITAS is an atmospheric Cherenkov telescope array designed to study astrophysical sources of very-high-energy gamma radiation. Located in southern Arizona, USA, the array consists of four 12 m-diameter imaging Cherenkov telescopes. All four telescopes have been deployed at the basecamp of the Whipple Observatory and began full operation in early 2007. This paper describes the operational status of VERITAS, outlines the initial performance parameters of the instrument, and presents the latest results that have been obtained.

VERITAS

VERITAS is a ground-based GeV-TeV gamma-ray observatory using an array of four large imaging Cherenkov telescopes (see Figure 1) [1]. It combines a large effective area ($> 3 \times 10^4$ m^2) over a wide energy range (100 GeV to 30 TeV) with good energy (10-20%) and angular resolution [2]. The high sensitivity of VERITAS allows the detection of sources with a flux of 10% of the Crab Nebula in under 1 hour of observations (5 σ detection). The angular resolution on an event-by-event basis is better than 0.14°. Sources of high-energy γ-rays can currently be located with a precision better than 2-3$'$ (this will improve to below 100$''$ with the installation of optical pointing monitors on each of the telescopes). The field of view of the system is 3.5° in diameter with an off-axis acceptance above 65% for offsets smaller than 1° from the camera center. This allows for the detection of extended sources and is well suited for sky surveys.

VERITAS is located at the basecamp of the Fred Lawrence Whipple Observatory in southern Arizona (1268 m a.s.l., $31^\circ 40' 30''$N, $110^\circ 57' 07''$W). The system is operated by an international collaboration of institutions from the U.S.A., Canada, Ireland and the U.K. Scientific observations with VERITAS started during the construction phase in spring 2006 with first two, then three (January 2007), and finally four telescopes (March 2007). A first light celebration for VERITAS took place in April 2007. VERITAS has been fully operational since March 2007 and is now running an extensive program of scientific observations.

The overall design of each of the four VERITAS telescopes is identical [3]. Each telescope employs a 12 m-diameter tessellated mirror of Davies-Cotton design with 12 m focal length and a to-

Figure 1: The VERITAS array of Cherenkov telescopes at the Fred Lawrence Whipple Observatory.

tal mirror area of $106\,\mathrm{m}^2$. The reflectivity of the mirrors is measured to be above 90% at 320 nm [4]. The laser-guided alignment of the 345 mirrors yields a point-spread function of $\sim 0.06^o$ [5]. The focal plane is equipped with a 499-element photomultiplier-tube (PMT) imaging camera [6]. Light cones installed in front of the camera increase the photon collection efficiency and shield the PMTs from ambient light. The three-level trigger system of the VERITAS array [7, 8] significantly suppresses background events due to local muons which are a problem in single-telescope operation. The typical array trigger rate is 220 Hz with a dead time of $\sim$10%. When triggered, the PMT signals in each telescope are digitized using 500 MS/s custom-built FADC electronics [9, 10]. The actual conditions of the system and at the site are constantly monitored [11, 12] and taken into account with a detailed calibration chain [13]. VERITAS observations can be analyzed by a number of independently developed analysis packages [14, 15]. All aspects of the event reconstruction have been extensively tested with simulations [2].

VERITAS observations 2006 - 2007

Although the scientific program of VERITAS started in early 2007, several sources were observed and detected during the construction phase. The objects studied are mainly part of the VERITAS key science projects, but comprise as well the observation of γ-ray bursts [16] and research on cosmic rays [17]. The key science projects comprise supernova remnants and pulsar wind nebulae, dark matter candidates, blazars, and a survey of three regions of the galactic plane with

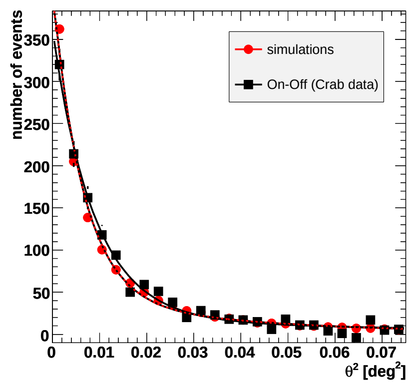

Figure 2: Θ^2 distribution for gamma rays recorded from the Crab Nebula in comparison with simulations of a point-like source (3-telescope array, see [2] for details).

a sensitivity of 5% of the Crab Nebula flux (beginning in late spring 2007). Some of the early results of the VERITAS science program are listed below; details and further references can be found in the referred VERITAS contributions to this conference.

The Crab Nebula is a strong, steady, point-like source of high-energy γ-rays. Observations of this source provide, apart from scientific results, many valuable insights into the performance of the instrument. The Crab Nebula was observed with different array configurations in 2006 and 2007 ($\sim$35 h with two telescopes and $\sim$3.5 h with three telescopes). For the 3-telescope observations, the total detection significance is $51.6\,\sigma$ with a mean γ-ray rate after standard cuts of 7.5 γ/min (Figure 2 and [20]). The measured energy spectrum of the

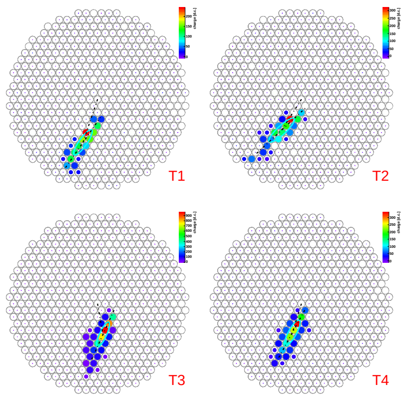

Figure 3: Camera view of a four-telescope event with VERITAS. The color scale indicates the integrated charge per channel.

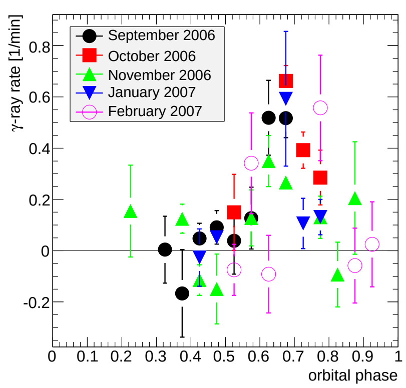

Figure 4: Rate of excess events versus orbital phase for five different orbits for LS I +61 303.

Crab Nebula for the two- and three-telescope data is consistent in shape and flux with previous results from other observatories. Another galactic object observed is the binary system LS I +61 303, a known emitter of high-energy γ-rays, detected by MAGIC [21]. LS I +61 303 was detected by VERITAS during several orbital cycles; the total significance for the whole data set is $8.8\,\sigma$ [22]. The observations have been accompanied by extensive X-ray monitoring with Swift and RXTE satellites [23]. The measured γ-ray rate is strongly variable and is modulated at an orbital period of 26.5 days, showing the strong dependence of particle acceleration and/or propagation on the relative position of the two objects in the system. The maximum flux appears in each orbital cycle approximately at apastron and corresponds to about 10% of the flux of the Crab Nebula (Figure 4).

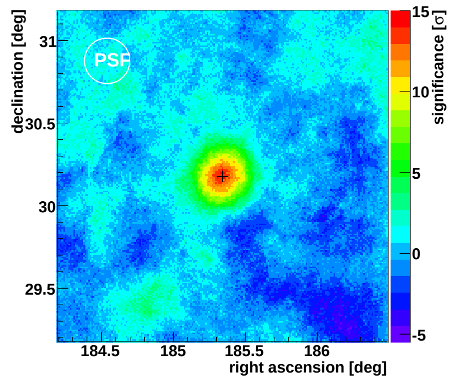

Figure 5: Significance map of the region around 1ES 1218 +304.

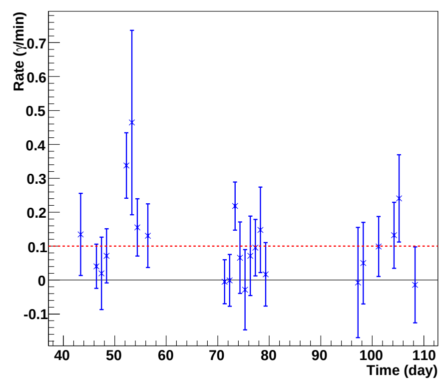

Figure 6: Light curve of very-high-energy γ-rays from the direction of M87.

Several supernova remnants and pulsar wind nebulae were observed [24, 25]; a highlight is the study of the source SNR IC 443. A number of potential TeV sources identified by the MILAGRO observatory [26] were coincidentally in the field of view during several hours of observation with VERITAS; new upper flux limits for these are presented in [27].

Various extra-galactic sources were observed with VERITAS. While new upper limits could be set on a number of AGN [28, 29], several were clearly detected (Markarian 421 and Markarian 501 [30], 1ES 1218 +304 [31], and M87 [32]). 1ES 1218 +304 is, with a redshift of z=0.182, one

of the most distant blazars observed in high-energy γ-rays [34]. It was detected by VERITAS during $\sim$17 h of observation with a total significance of $10\,\sigma$ and a typical γ-ray rate of 0.3 γ/min (Figure 5). M87, on the other hand, is the only active galactic nucleus seen in high energy γ-rays which is not of the blazar type. The H.E.S.S. Collaboration recently reported rapid variability and an unexpectedly hard TeV energy spectrum for M87 [35]. The source has been detected with VERITAS and Figure 6 shows the light curve for early 2007. The observation of blazars with VERITAS is closely connected to the AGN monitoring program of the Whipple telescope [33].

Summary

The construction of the VERITAS array of imaging Cherenkov telescopes is now completed; the system has achieved excellent performance, with a measured sensitivity for the 3-telescope array corresponding to 10% of the Crab Nebula flux in 1.2 h and a Monte Carlo derived sensitivity for four telescopes of under 1 h for the same flux level. The various contributions of the VERITAS collaboration to this conference demonstrate the great potential of the system for the discovery of new γ-ray sources and for detailed morphological and spectral studies.

Acknowledgments

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